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The Temperature Dependent, Infrared Absorption Cross-  
Sections for the Chlorofluorocarbons: CFC-11, CFC-12, CFC-  
13, CFC-14, CFC-2 2, CFC-113, CFC-114, and CFC-115

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The infrared absorption cross-sections for eight commonly used halogenated methanes and ethanes have been measured as a function of temperature from 203 to 293 K. High resolution spectra ( $0.03\text{ cm}^{-1}$ ) have been used to derive integrated band strengths and peak cross-sections associated with the spectral features in the infrared region from 600 to  $1500\text{ cm}^{-2}$ . The values obtained in this study are compared to those from previous reports, and recommendations are made for uses in atmospheric sensing and radiative energy transfer models. The observed temperature dependence in the spectral features is also discussed.

# TEMPERATURE DEPENDENCE OF THE INFRARED ABSORPTION CROSS SECTIONS OF CARBON TETRACHLORIDE

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Infrared absorption cross sections for carbon tetrachloride are reported over the range 730 to 825  $\text{cm}^{-1}$  at four different temperatures (298, 273, 248, and 223 K). The absorption cross sections were measured using Fourier transform spectroscopy at a spectral resolution of 0.05  $\text{cm}^{-1}$ . The integrated band intensity for this spectral region was found to be  $(5.75 \pm 0.30) \times 10^{-1} / \text{cm}^2 \text{ molecule}^{-1} \text{ cm}^{-1}$ , independent of temperature. The absorption cross sections were found to be essentially independent of spectral resolution (between 0.05 and 0.25  $\text{cm}^{-1}$ ) and foreign gas pressure (0-1 atm at 298 K, 0-200 torr at 223 K), although changes of about 5 to 10 % were noted in the structured regions of the spectrum. Our measured band intensity appears to be about 15 % higher than recently published data. These differences are discussed in terms of their effect on previously reported stratospheric  $\text{CCl}_4$  altitude profiles.

## High-resolution absorption cross sections of chlorine nitrate in the $\nu_2$ band region around $1292\text{ cm}^{-1}$ at stratospheric temperatures

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The infrared absorption spectrum of  $\text{ClONO}_2$  has been recorded between 500 and  $1600\text{ cm}^{-1}$  at temperatures between 188 K and 222 K and resolutions of up to  $0.004\text{ cm}^{-1}$ . The infrared absorption cross sections were determined for the  $\nu_2$  band between  $1260$  and  $1320\text{ cm}^{-1}$ . The cross sections (with  $0.025\text{ cm}^{-1}$  resolution for the central Q branch absorption maximum at  $1292.68\text{ cm}^{-1}$ ) are (in  $10^{-18}\text{ cm}^2\text{ molecule}^{-1}$ )  $3.12 \pm 0.06$  at 201 K,  $3.45 \pm 0.15$  at 211 K, and  $3.31 \pm 0.06$  at 222 K. The influence of resolution on the cross section of the Q branch maximum only for resolutions between  $0.025$  and  $0.100\text{ cm}^{-1}$ . In the P and R branches, the cross sections change considerably with increasing resolution. The new absorption cross sections are important for the determination of stratospheric  $\text{ClONO}_2$  concentrations from atmospheric infrared absorption spectra and for atmospheric transmission in the spectral region around  $1292\text{ cm}^{-1}$ .

## INFRARED ABSORPTION CROSS SECTIONS FOR N<sub>2</sub>O<sub>5</sub>

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Laboratory measurements of absolute infrared absorption cross sections for three strong bands of N<sub>2</sub>O<sub>5</sub> have been used as a function of temperature from 233 to 350 K. The results of this study confirm most of the recent laboratory studies, indicating reasonable confidence in cross sections for this molecule which is of potential use in its identification and measurement in atmosphere and in laboratory systems. Beer-Lambert linearity is confirmed and the effect of instrumental resolution on integrated intensities as well as peak cross sections is reported.

## Absolute Absorption Coefficients of ClONO<sub>2</sub> Infrared Bands at Stratospheric Temperatures

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Fourier-transform absorption spectroscopy has been used in the laboratory to obtain absolute absorption coefficients  $\sigma(\nu)$  in infrared bands of ClONO<sub>2</sub> in the 700-1800 cm<sup>-1</sup> spectral region. These data have been obtained over a temperature range (213-296 K) corresponding to stratospheric temperatures. The results are therefore applicable to retrievals of stratospheric ClONO<sub>2</sub> from remote-sensing observations. Room temperature absorption coefficients are some 25% larger than previously reported values, and large temperature dependences in the absorption coefficients have been observed. The  $\nu$  and  $\nu_2$  bands behave as simple fundamentals of a system which has low-energy vibrational or torsional modes, with little contribution from hot bands over the temperature range used. The intensity in the  $\nu_2$  Q branch increased by 53% over the temperature range 296-213 K. A similar increase was observed for the  $\nu_4$  Q branch, and significant hot-band features were seen in the  $\nu_3$ ,  $\nu_4$  spectral region. The  $\nu_4$  Q branch and the  $\nu_2$  Q branch were observed to obey the Beer-Lambert law over the range of pressure, temperature, absorber amount, and resolution employed. The absorption coefficients in the  $\nu_4$  Q branch and in the  $\nu_2$  band were modeled by equispaced absorption lines, each characterized by a central frequency, strength, lower-state energy, and pressure-broadened width.

# MEASUREMENT OF THE ABSORPTION CROSS-SECTIONS OF CFC-11 AT CONDITIONS REPRESENTING VARIOUS MODEL ATMOSPHERES

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Abstract-Absorption cross-sections,  $k$ , ( $\text{cm}^2 \text{ atm}^{-1}$ ), have been measured in the 9.2 and 11.8,  $\mu\text{m}$  bands of *CFC-11* ( $\text{CCl}_3\text{F}$ ) using a high-resolution Fourier transform spectrometer. Temperature and total ( $\text{N}_2$ -broadening) pressure have been varied to obtain results at conditions representative of the atmosphere. The measured absolute intensities (in units of  $10^{-20} \text{ cm}^2 \text{ molecule}^{-1}$ ) of the 9.2 and 11.8,  $\mu\text{m}$  bands are  $2.591 \pm 0.013$  and  $6.974 \pm 0.038$ , respectively.



# SPECTRAL ABSORPTION-COEFFICIENT DATA ON HCFC-22 AND SF<sub>6</sub> FOR REMOTE-SENSING APPLICATIONS

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Abstract-Spectral absorption-coefficients (cross-sections)  $k$ , ( $\text{cm}^{-1} \text{ atm}^{-1}$ ) have been  
treasured in the 7.62, 8.97, and 12.3  $\mu\text{m}$  bands of HCFC-22 ( $\text{CHClF}_2$ ) and the 10.6  $\mu\text{m}$   
bands of SF<sub>6</sub> employing a high-resolution Fourier-transform spectrometer. Temperature  
and total pressure have been varied to simulate conditions corresponding to tropospheric  
and stratospheric layers in the atmosphere. The  $k_v$  are compared with values measured by  
us previously using a tunable diode laser spectrometer and with the appropriate entries in  
HITRAN and GEISA, two of the databases known to the atmospheric scientist. The  
measured absolute intensities of the bands are compared with previously published values.

# THERMAL INFRARED ABSORPTION COEFFICIENTS OF CFC-12 AT ATMOSPHERIC CONDITIONS

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Abstract-Spectral absorption coefficients  $k_a$  ( $\text{cm}^{-1} \text{atm}^{-1}$ ) have been measured in the 9 and 11  $\mu\text{m}$  bands of CFC-12 ( $\text{CF}_2\text{Cl}_2$ ) using a high-resolution Fourier transform spectrometer. Temperature and total (broadening) pressure have been varied to obtain results at conditions representative of tropospheric and stratospheric layers of the atmosphere. The measured absolute intensities (in units of  $10^{-17} \text{cm.molecule}^{-1}$ ) of the 9 and 11  $\mu\text{m}$  bands are  $7.595 \pm 0.070$  and  $5.750 \pm 0.068$ , respectively.

# INFRARED BAND STRENGTHS AND ABSORPTION CROSS-SECTIONS OF HFC-32 VAPOUR

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Abstract Infrared absorbance cross-sections and integrated band strengths for HFC-32 (difluoromethane,  $\text{CH}_2\text{F}_2$ ) vapour have been determined from laboratory measurements at eight temperatures (203, 212, 222, 243, 253, 264, 287, and 297 K) for the region 600-1900  $\text{cm}^{-1}$  at 0.03  $\text{cm}^{-1}$  instrument resolution, by Fourier transform infrared spectroscopy. In addition, air-broadened spectra of HFC-32 vapour have been recorded at 203, 251, and 297K at pressures of 5, 20, and 100 kPa air.

**MEASUREMENTS OF THE NO<sub>2</sub> ABSORPTION  
CROSS-SECTION FROM 42 000 cm<sup>-1</sup> TO 10 000 cm<sup>-1</sup> (238-  
1000 nm) AT 220 K AND 294 K**

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The NO<sub>2</sub> absorption cross-section has been measured from 42 000 to 10 000 cm<sup>-1</sup> (238-1000 nm) with a Fourier transform spectrometer (at the resolution of 2 cm<sup>-1</sup>, 0.01 nm at 240 nm to 0.2 nm at 1000 nm) and a 5 m temperature controlled multiple reflection cell. The uncertainty on the cross-section is estimated to be less than 3% below 40 000 cm<sup>-1</sup> ( $\lambda > 250$  nm) at 294 K, 3% below 30 000 cm<sup>-1</sup> ( $\lambda > 333$  nm) at 220 K, but reaches 10% for higher wavenumbers. Temperature and pressure effects have been observed. Comparison with data from the literature generally shows a good agreement for wavenumbers between 37 500 and 20 000 cm<sup>-1</sup> (267-500 nm). Outside these limits, the difference can reach several percent.

# INFRARED ABSORPTION CROSS-SECTIONS AND INTEGRATED ABSORPTION INTENSITIES OF HFC-134 AND HFC-143a VAPOUR

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Infrared absorption cross-sections and integrated absorption intensities of HFC-134 (1,1,2,2-tetrafluoroethane) and HFC-143a (1,1,1-trifluoroethane) vapour have been determined from laboratory measurements at six temperatures (203, 213, 233, 253, 273 and 297 K) for the region  $560\text{-}1900\text{ cm}^{-1}$  (5.3-17.9  $\mu\text{m}$ ) at  $0.03\text{ cm}^{-1}$  instrument resolution, by Fourier transform infrared spectroscopy. In addition, air-broadened spectra have been recorded at 297 K and pressures of 5, 20 and 100 kPa air. Inter-comparisons between this work and previous studies have been made where possible.

HIGH RESOLUTION ABSORPTION CROSS-SECTION  
MEASUREMENTS OF SO<sub>2</sub> AT 213 K IN THE  
WAVELENGTH REGION 172-240 nm

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Laboratory measurements at high resolution of the absorption cross section of SO<sub>2</sub> at the temperature 213 K have been performed in the wavelength region 172-240 nm with a 6.65 m scanning spectrometer/spectrograph operated at an instrumental width of 0.002 nm. The measured cross sections are presented graphically in representative wavelength regions and are available throughout the region 172-240 nm at wavenumber intervals of 0.4-0.1 cm<sup>-1</sup> as a numerical tabulation stored on magnetic tape from the National Space Science Data Center, NASA/Goddard Space Flight Center, Greenbelt, MD 20771, U.S.A. The measured cross sections, which are relevant to the photochemistry of planetary atmospheres, possess significantly more spectroscopic structure, and are more accurate, than previous measurements made at lower resolution.

HIGH RESOLUTION ABSORPTION CROSS-SECTION  
MEASUREMENTS OF N<sub>2</sub>O AT 295-299 K IN THE  
WAVELENGTH REGION 170-222 nm

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High resolution absorption cross-section measurements of N<sub>2</sub>O at 295-299 K have been performed in the wavelength region 170-222 nm with a 6.65 m scanning spectrometer/spectrograph of sufficient resolution to yield cross-sections that are independent of the instrumental function. The measured cross-sections are presented graphically and are available throughout the region 44925-58955 cm<sup>-1</sup> at intervals of 0.1-0.2 cm<sup>-1</sup> as a numerical tabulation stored on magnetic tape from the National Space Science Data Center, NASA;Goddard Space Flight Center, Greenbelt, MD 20771, U.S.A. Previously unresolved details of the banded structure which is superposed on the continuous absorption in the region 174-190nm are observed.

## Infrared Cross Sections and Global Warming Potentials of 10 Alternative Hydrohalocarbons

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Absorption cross sections have been obtained in the infrared atmospheric window, between 600 and 1500  $\text{cm}^{-1}$ , for 10 alternative hydrohalocarbons: HCFC22, HCFC123, HCFC124, HCFC141b, HCFC142b, HCFC225ca, HCFC225cb, HFC125, HFC134a and HFC152a. The measurements were made at three temperatures (287 K, 270 K and 253 K) with a Fourier transform spectrometer operating at 0.03  $\text{cm}^{-1}$  apodized resolution. Integrated cross sections have been introduced into a two-dimensional radiative-chemical-dynamical model in order to calculate the global warming potential (GWP) of each gas.